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Lee

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(54) **SPIRAL INDUCTOR WITH MULTI-TRACE STRUCTURE**

(75) Inventor: **Sheng-Yuan Lee**, Taipei (TW)

(73) Assignee: **Via Technologies, Inc.**, Hsin-Tien, Taipei (TW)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
H01F 5/00 (2006.01)

(52) **U.S. Cl.** **336/200**

(58) **Field of Classification Search** 336/65, 336/83, 200, 232; 257/531
See application file for complete search history.

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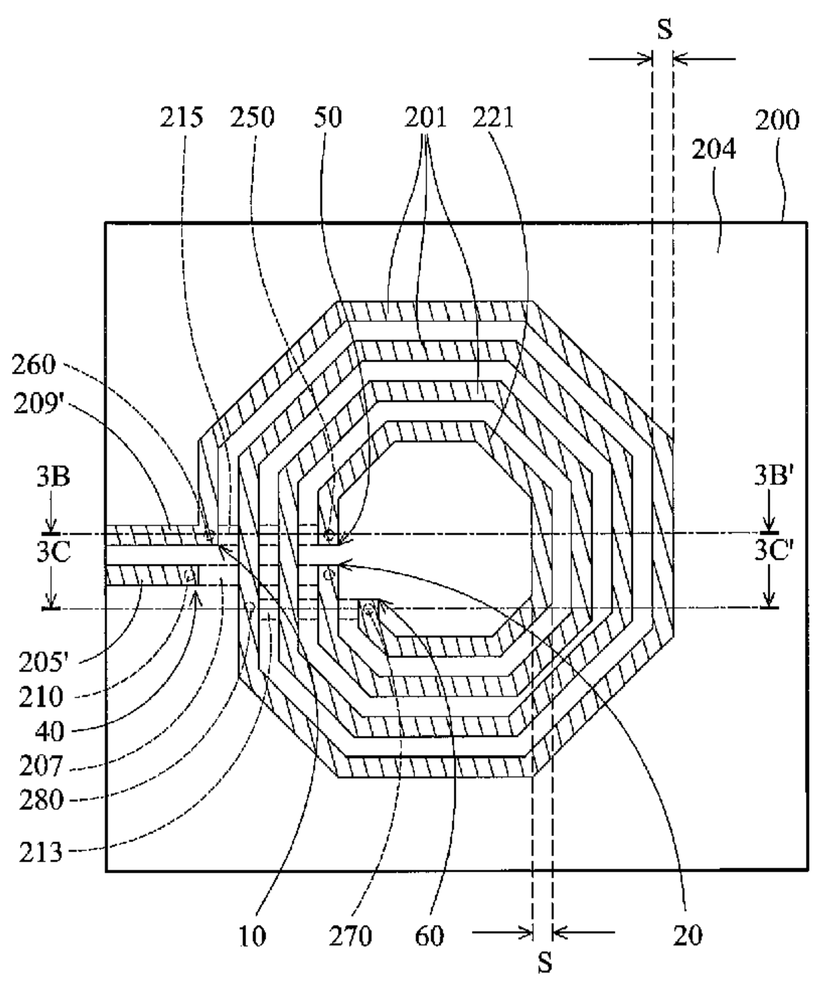
Primary Examiner—Tuyen Nguyen
(74) *Attorney, Agent, or Firm*—Thomas, Kayden, Horstemeyer & Risley

(57) **ABSTRACT**

A spiral inductor with a multi-trace structure having an insulating layer disposed on a substrate. A first spiral conductive trace with multiple turns is disposed on the insulating layer, wherein the outermost turn and the innermost turn of the first spiral conductive trace have a first end and a second end, respectively, and one of the first and second ends is connected to ground. A second spiral conductive trace with a single turn is disposed on the insulating layer and adjacent to the first spiral conductive trace, wherein the second spiral conductive trace is electrically connected to the turn that is connected to the ground and belongs to the first spiral conductive trace. The first spiral conductive trace has a relative outside and a relative inside, wherein the end of the first spiral conductive trace connected to ground and the second spiral conductive trace are located at different sides respectively.

6 Claims, 5 Drawing Sheets



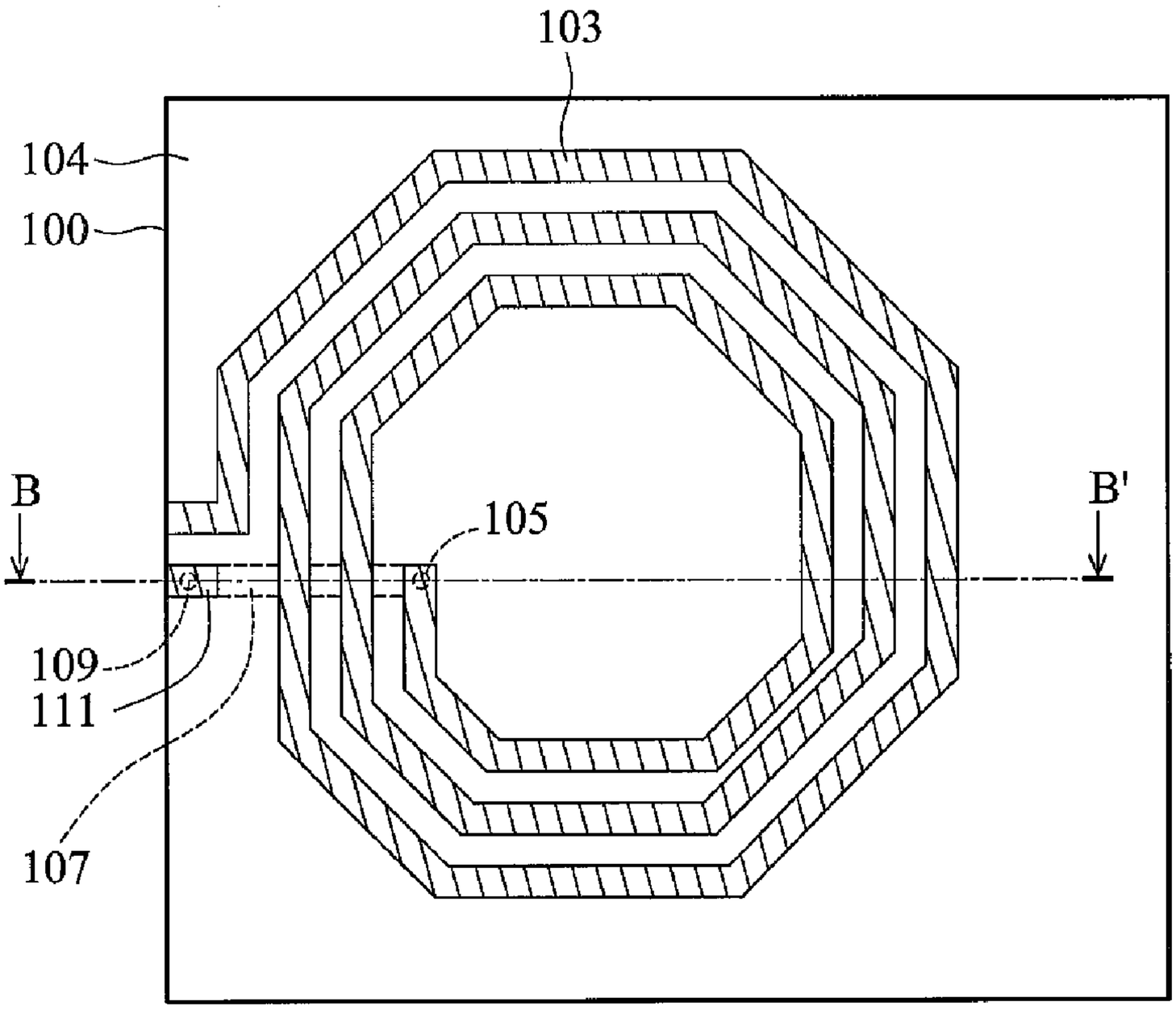


FIG. 1A (PRIOR ART)

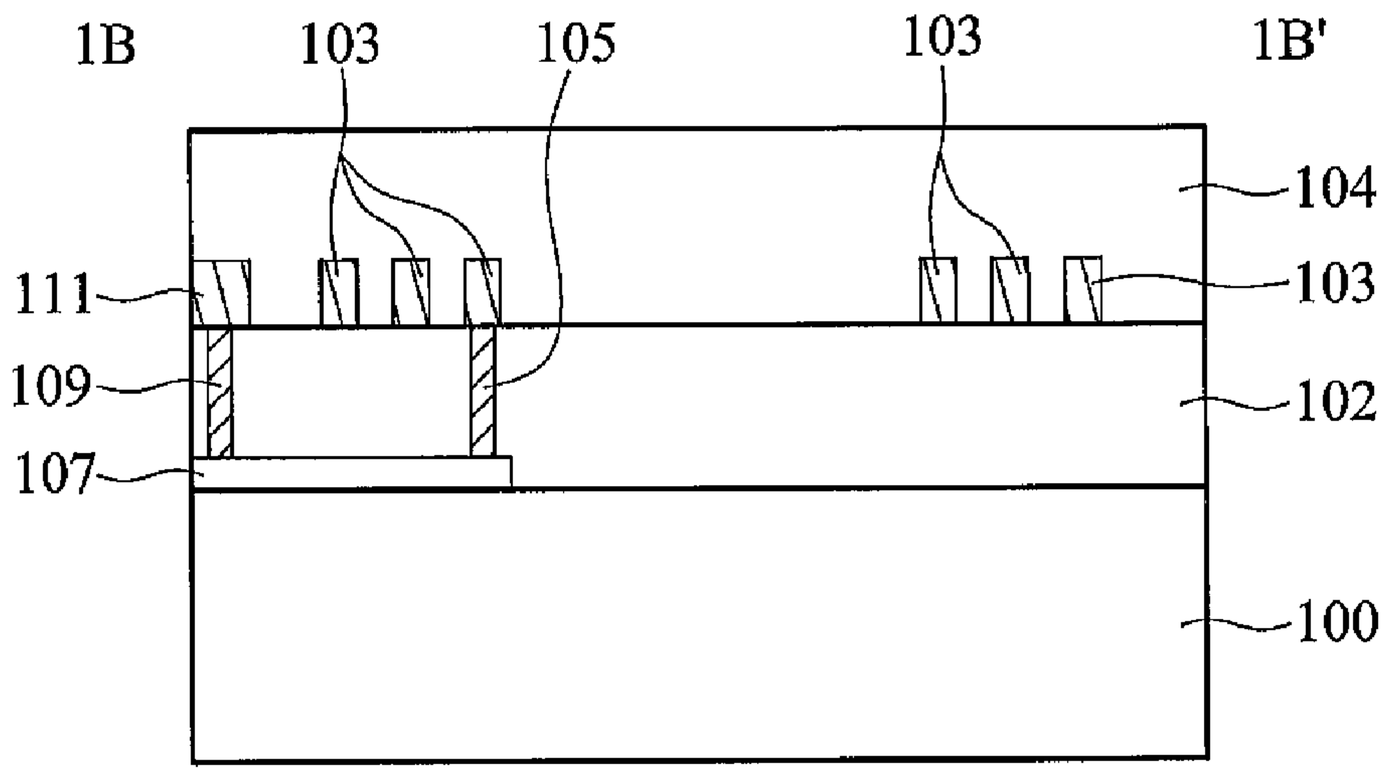


FIG. 1B (PRIOR ART)

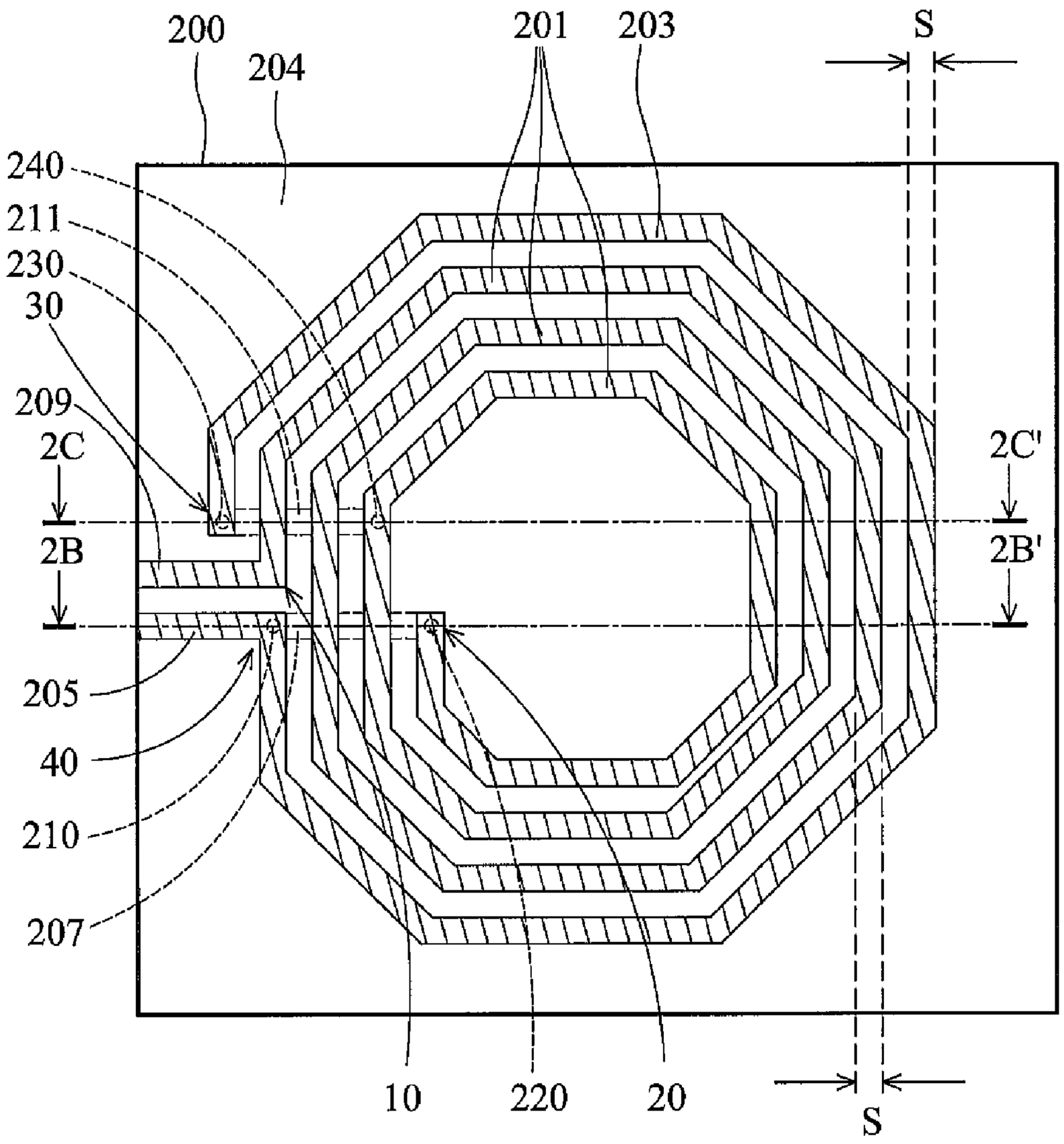

200
204
201
203
S
240
211
230
30
209
2C
2B
205
40
210
207
2C'
2B'
10
220
20
S

FIG. 2A

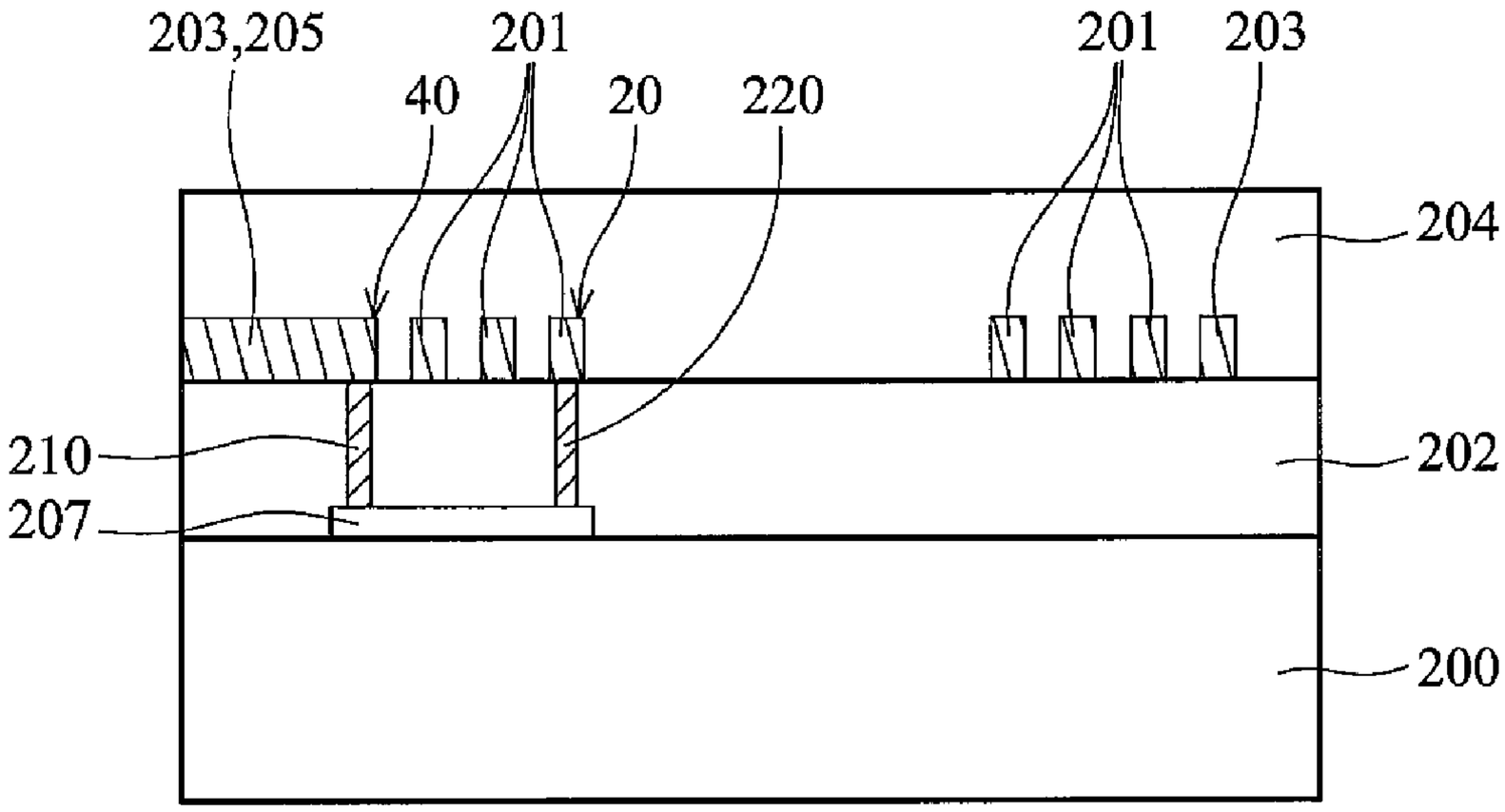

203,205
201
40
20
220
201
203
204
210
207
202
200

FIG. 2B

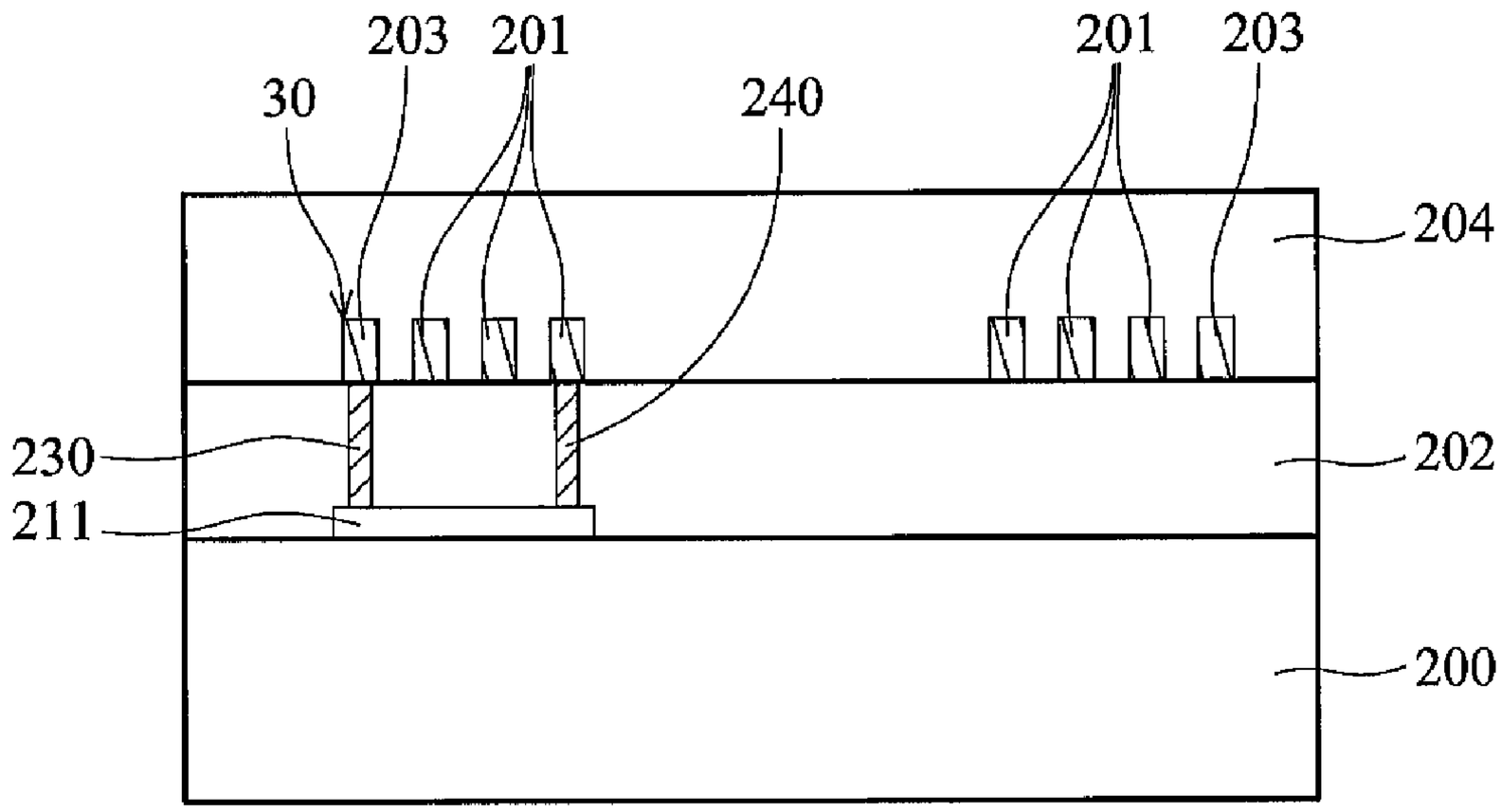

203
201
30
240
201
203
204
230
211
202
200

FIG. 2C

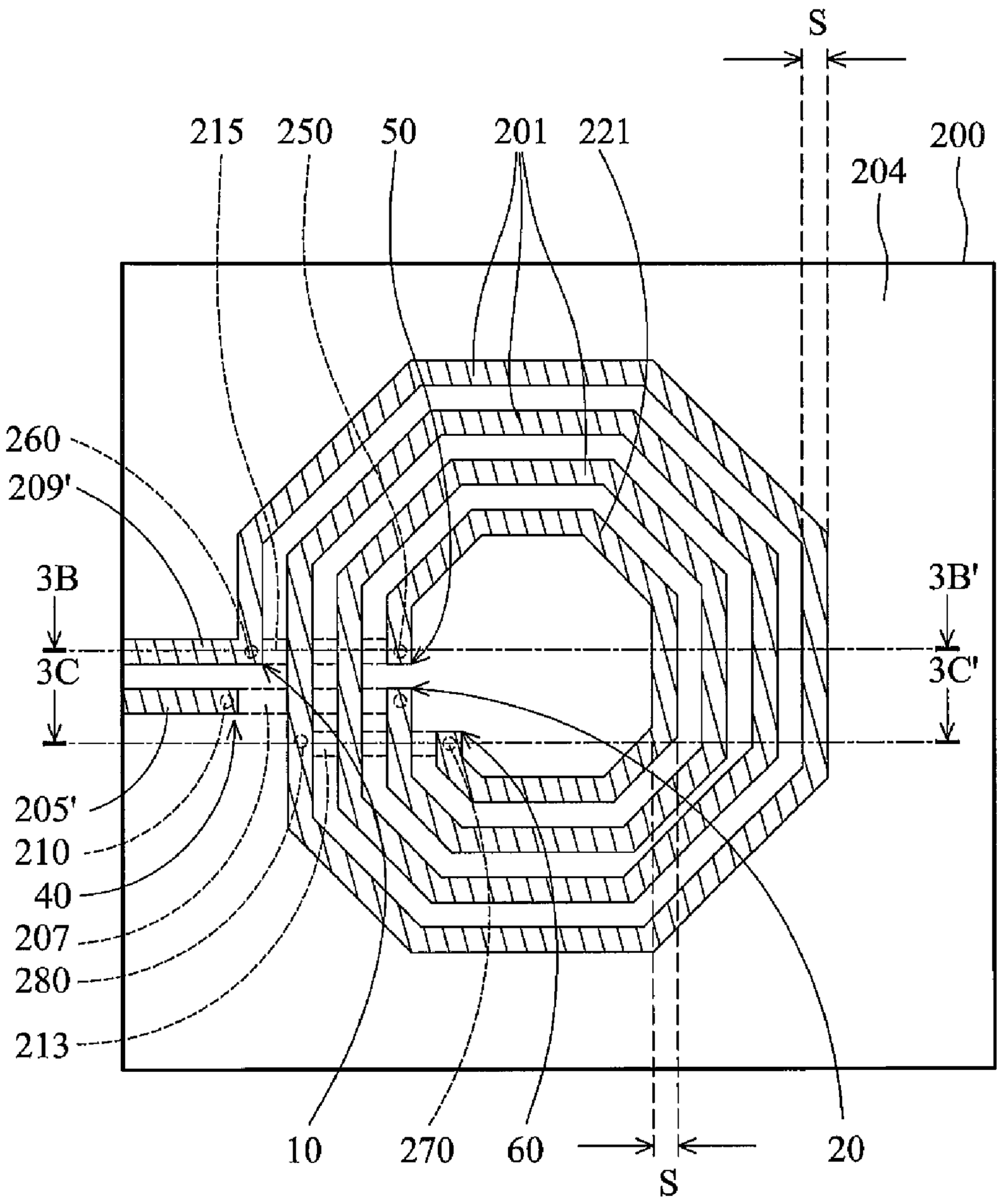

S
215
250
50
201
221
200
204
260
209'
3B
3C
3B'
3C'
205'
210
40
207
280
213
10
270
60
S
20

FIG. 3A

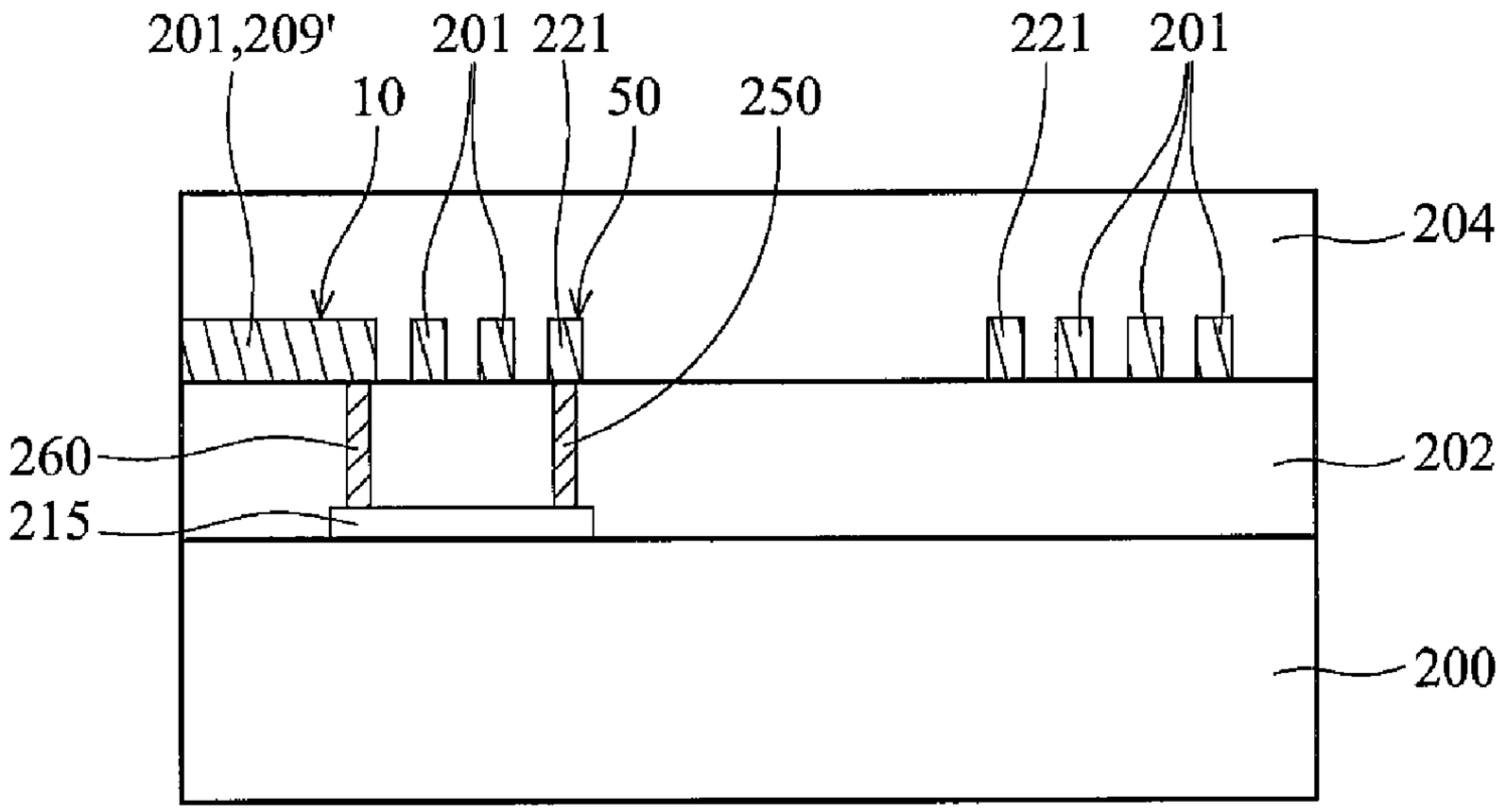

201,209'
201
221
221
201
10
50
250
204
260
202
215
200

FIG. 3B

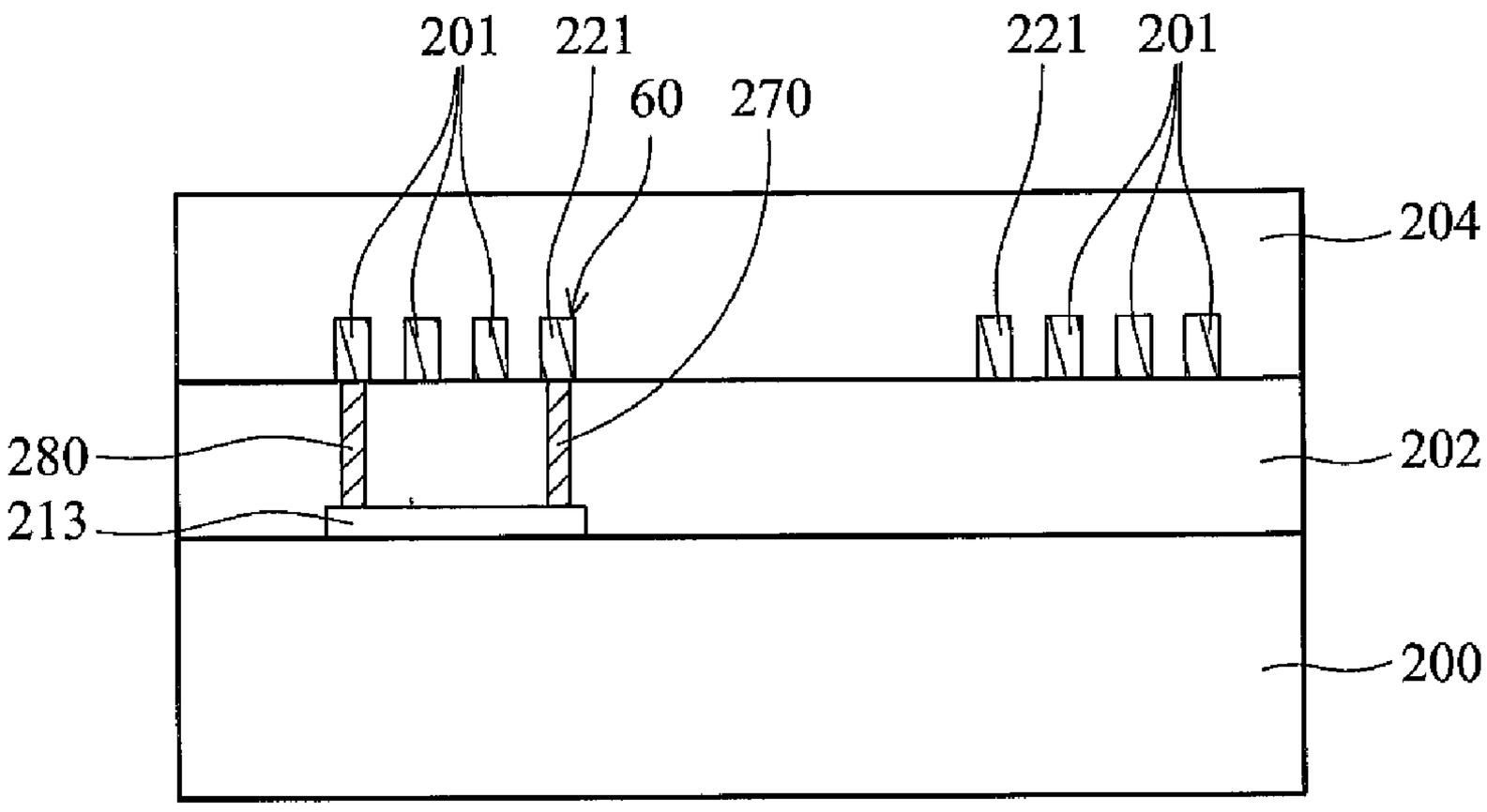

201
221
60
270
221
201
204
280
202
213
200

FIG. 3C

SPIRAL INDUCTOR WITH MULTI-TRACE STRUCTURE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Divisional of U.S. patent application Ser. No. 11/774,094, filed on Jul. 6, 2007, which claims priority of Taiwan Patent Application No. 096101237, filed on Jan. 12, 2007, the entirety of which are incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to semiconductor integrated circuits and more particularly to an on-chip inductor with multi-trace structure.

2. Description of the Related Art

Many digital and analog elements and circuits have been successfully applied to semiconductor integrated circuits. Such elements may include passive components, such as resistors, capacitors, or inductors. Typically, a semiconductor integrated circuit includes a silicon substrate. One or more dielectric layers are disposed on the substrate, and one or more metal layers are disposed in the dielectric layers. The metal layers may be employed to form on-chip elements, such as on-chip inductors, by current semiconductor technologies.

Conventionally, an on-chip inductor is formed over a semiconductor substrate and employed in integrated circuits designed for the radio frequency (RF) band. FIGS. **1**A and **1**B illustrate a plan view of a conventional on-chip inductor with a planar spiral configuration and a cross-section along **1**B-**1**B' line shown in FIG. **1**A, respectively. The on-chip inductor is formed in a dielectric layer **104** on a substrate **100**, comprising a spiral conductive trace **103** and an interconnect structure. The spiral conductive trace **103** is embedded in the dielectric layer **104**. The interconnect structure includes conductive plugs **105** and **109** and a conductive trace **107** embedded in a dielectric layer **102** and a signal output/input conductive trace **111** embedded in the dielectric layer **104**. The dielectric layer **102** is disposed between the dielectric layer **104** and the substrate **100**. An internal circuit of the chip or an external circuit may provides a current passing through the coil, which includes the conductive trace **103**, the conductive plugs **105** and **109**, the conductive trace **107**, and the signal output/input conductive trace **111**.

A principle advantage of the planar spiral inductor is the increased level of circuit integration due to the reduced number off-chip circuit elements and the complex interconnections required thereby. Moreover, the planar spiral inductor can reduce parasitic effect induced by the bond pads or bond wires between on-chip and off-chip circuits.

As integrated circuit (IC) designs have progressed, there has been an increased interest in integrating several different functions on a single chip while minimizing process complexity and any resulting impact on manufacturing yield. This integration of several different functions on a single chip is known as system on chip (SOC). Additionally, with the rapid development of communication systems, an SOC typically includes radio frequency (RF) circuits and digital or baseband circuits. Since the RF circuits in an SOC are smaller than the digital or baseband circuits, chip fabrication employs a digital or baseband circuit process. Accordingly, inductor traces in SOC are thinner compared to the inductors of general RF circuits, resulting reduced quality factor (Q value).

Since the performance of integrated circuit devices is based on the Q value of the on-chip inductors, there is a need to develop an on-chip inductor with increased Q value.

BRIEF SUMMARY OF INVENTION

A detailed description is given in the following embodiments with reference to the accompanying drawings.

A spiral inductor with a multi-trace structure is provided. An embodiment of a spiral inductor with a multi-trace structure comprises an insulating layer disposed on a substrate. A first spiral conductive trace with multiple turns is disposed on the insulating layer, wherein the outermost turn and the innermost turn of the first spiral conductive trace have a first end and a second end, respectively, and one of the first and second ends is connected to ground. A second spiral conductive trace with a single turn is disposed on the insulating layer and adjacent to the first spiral conductive trace, wherein the second spiral conductive trace is electrically connected to the turn that is connected to the ground and belongs to the first spiral conductive trace. The first spiral conductive trace has a relative outside and a relative inside, wherein the end of the first spiral conductive trace connected to ground and the second spiral conductive trace are located at different sides respectively.

Another embodiment of a spiral inductor with a multi-trace structure comprises an insulating layer disposed on a substrate. A first spiral conductive trace with multiple turns is disposed on the insulating layer, wherein the outermost turn of the first spiral conductive trace is connected to ground. At least one second spiral conductive trace with a single turn is disposed on the insulating layer and located inside the innermost turn of the first spiral conductive trace, wherein the second spiral conductive trace is connected to the outermost turn of the first spiral conductive trace to form the multi-trace structure.

Another embodiment of a spiral inductor with a multi-trace structure comprises an insulating layer disposed on a substrate. A first spiral conductive trace with multiple turns is disposed on the insulating layer, wherein the innermost turn of the first spiral conductive trace is connected to ground. At least one second spiral conductive trace with a single turn is disposed on the insulating layer and located outside the outermost turn of the first spiral conductive trace, wherein the second spiral conductive trace is connected to the innermost turn of the first spiral conductive trace to form the multi-trace structure.

BRIEF DESCRIPTION OF DRAWINGS

The invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

FIG. **1**A is a plan view of a conventional on-chip inductor with a planar spiral configuration;

FIG. **1**B shows a cross-section along **1**B-**1**B' line shown in FIG. **1**A;

FIG. **2**A is a plan view of an embodiment of a spiral inductor with a multi-trace structure;

FIG. **2**B shows a cross section along **2**B-**2**B' line shown in FIG. **2**A;

FIG. **2**C shows a cross section along **2**C-**2**C' line shown in FIG. **2**A;

FIG. **3**A is a plan view of an embodiment of a spiral inductor with a multi-trace structure;

FIG. **3**B shows a cross section along **3**B-**3**B' line shown in FIG. **3**A; and

FIG. **3**C shows a cross section along **3**C-**3**C' line shown in FIG. **3**A.

DETAILED DESCRIPTION OF INVENTION

The following description is of the best-contemplated mode of carrying out the invention. This description is pro-

vided for the purpose of illustrating the general principles of the invention and should not be taken in a limiting sense. The scope of the invention is best determined by reference to the appended claims. The inductor of the invention will be described in the following with reference to the accompanying drawings.

The invention relates to a spiral inductor with a multi-trace structure, comprising a spiral conductive trace with multiple turns. The outermost turn and the innermost turn of the spiral conductive trace have a first end and a second end, respectively. If the first end of the outermost turn of the spiral conductive trace is connected to the ground, there is an additional spiral conductive trace with a single turn located inside the innermost turn of the spiral conductive trace and electrically connected in parallel to the outermost turn of the spiral conductive trace. Additionally, if the second end of the innermost turn of the spiral conductive trace is connected to ground, an additional spiral conductive trace with a single turn is located outside the outermost turn of the spiral conductive trace and electrically connected in parallel to the innermost turn of the spiral conductive trace. That is, the additional spiral conductive trace with a single turn and the grounding end of the turn of the spiral conductive trace are located inside and outside the spiral conductive trace with multiple turns, respectively, or located outside and inside the spiral conductive trace with multiple turns, respectively.

Referring to FIGS. **2**A to **2**C, in which FIG. **2**A is a plan view of an embodiment of a spiral inductor with a multi-trace structure, FIG. **2**B is a cross section along **2**B-**2**B' line shown in FIG. **2**A and FIG. **2**C is a cross section along **2**C-**2**C' line shown in FIG. **2**A.

The spiral inductor comprises a spiral conductive trace **201** with multiple turns embedded in an insulating layer, at least one spiral conductive trace **203** with a single turn and connecting traces **207** and **211**, in which the insulating layer is disposed on a substrate **200**. The substrate **200** may include a silicon substrate or other well-known semiconductor substrate. The substrate **200** may include various elements, such as transistors, resistors, or other well-known semiconductor elements. Moreover, the substrate **200** may also include other conductive layers (e.g. copper, aluminum, or alloy thereof) and insulating layers (e.g. silicon oxide, silicon nitride, or low-k dielectric material). Hereinafter, to simplify the diagram, only a flat substrate is depicted.

In this embodiment, the insulating layer may comprise dielectric layers **202** and **204** successively disposed on the substrate **200**. The dielectric layers **202** and **204** may include silicon oxide, silicon nitride, or low-k dielectric material.

The spiral conductive trace **201** with multiple turns is embedded in the dielectric layer **204** and may comprise, for example, three turns. The spiral conductive trace **201** with multiple turns may be circular, rectangular, hexagonal, octagonal or polygonal. Hereinafter, only an exemplary octagonal spiral conductive trace is depicted. The outermost turn and the innermost turn of the spiral conductive trace **201** with multiple turns have a first end **10** and a second end **20**, respectively, in which a signal output/input trace **209** is located at the first end **10** to serve as a signal output/input terminal. Moreover, the spiral conductive trace **201** with multiple turns has a line width S and may comprise copper, aluminum or alloy thereof.

The second end **20** of the innermost turn of the spiral conductive trace **201** with multiple turns is connected to ground. Since the grounding second end **20** belongs the innermost turn of the spiral conductive trace **201** with multiple turns, there is a spiral conductive trace **203** with a single turn disposed outside the outermost turn of the spiral conductive trace **201** with multiple turns, and the spiral conductive trace **203** with a single turn is electrically connected in parallel to the innermost turn of the spiral conductive trace **201** with multiple turns.

The spiral conductive trace **203** with a single turn is embedded in the insulating layer **204** and located outside the outermost turn of the spiral conductive trace **201** with multiple turns. That is, the spiral conductive trace **203** with a single turn is substantially parallel to and surrounds the spiral conductive trace **201** with multiple turns.

The spiral conductive trace **203** with a single turn has a first end **30** and a second end **40**, wherein the second end **40** corresponds to the second end **20** of the spiral conductive trace **201** with multiple turns. Moreover, a signal output/input trace **205** is located at the second end **40** of the spiral conductive trace **203** with a single turn to serve as a signal output/input terminal. In this embodiment, the signal output/input trace **205** is connected to ground. The spiral conductive trace **203** with a single turn has a line width substantially the same as the line width S of the spiral conductive trace **201** with multiple turns and may comprise copper, aluminum or alloy thereof.

The connecting traces **207** and **211** may comprise copper, aluminum or alloy thereof and are embedded in the dielectric layer **202** underlying the dielectric layer **204**, thereby connecting the innermost turn of the spiral conductive trace **201** with multiple turns and the spiral conductive trace **203** with a single turn in parallel to form a multi-trace structure. For example, the connecting trace **207** is disposed between the second end **20** of the spiral conductive trace **201** with multiple turns and the second end **40** of the spiral conductive trace **203** with a single turn and is electrically connected between the innermost turn of the spiral conductive trace **201** with multiple turns and the spiral conductive trace **203** with a single turn by conductive plugs **210** and **220** disposed in the dielectric layer **202**, respectively, as shown in FIG. **2**B. Here, the innermost turn of the spiral conductive trace **201** with multiple turns is connected to ground through the connecting trace **207**, the conductive plugs **210** and **220** and the signal output/input trace **205** of the spiral conductive trace **203** with a single turn. Moreover, the connecting trace **211** is disposed between the innermost turn of the spiral conductive trace **201** with multiple turns and the first end **30** of the spiral conductive trace **203** with a single turn and is electrically connected between the innermost turn of the spiral conductive trace **201** with multiple turns and the spiral conductive trace **203** with a single turn by conductive plugs **230** and **240** disposed in the dielectric layer **202**, respectively, as shown in FIG. **2**C.

Additionally, note that although the spiral conductive trace **201** with three turns is depicted in an exemplary embodiment, the spiral conductive trace **201** may comprise two or more than three turns. Moreover, although the spiral conductive trace **203** with a single turn and the innermost turn of the spiral conductive trace **201** with multiple turns are connected in parallel in an exemplary embodiment, the spiral conductive trace **201** with multiple turns may be connected in parallel to more than two spiral conductive traces with a single turn.

Referring to FIGS. **3**A to **3**C, in which FIG. **3**A is a plan view of an embodiment of a spiral inductor with multi-trace structure, FIG. **3**B is a cross section along **3**B-**3**B' line shown in FIG. **3**A and FIG. **3**C is a cross section along **3**C-**3**C' line shown in FIG. **3**A. If the elements in FIGS. **3**A to **3**C are the same as those in FIGS. **2**A to **2**C, the elements will be labeled as the same reference numbers as FIGS. **2**A to **2**C use and will not be described again.

In this embodiment, the spiral inductor comprises a spiral conductive trace **201** with multiple turns and at least one spiral conductive trace **221** with a single turn embedded in a dielectric layer **204**, and connecting traces **207**, **213** and **215** embedded in a dielectric layer **202**. Signal output/input traces **209'** and **205'** are disposed in the dielectric layer **204** and

respectively corresponding to the first and second ends **10** and **20** of the spiral conductive trace **201** with multiple turns to serve as output/input terminals. The output/input trace **209'** is formed by laterally extending the first end **10** of the spiral conductive trace **201** with multiple turns and the output/input trace **205'** is electrically connected to the second end **20** of the spiral conductive trace **201** with multiple turns through the connecting trace **207** and conductive plugs **210** and **220**. Here, the output/input trace **209'** located at the first end **10** of the spiral conductive trace **201** with multiple turns is connected to ground.

Moreover, in this embodiment, the first end **10** of the outermost turn of the spiral conductive trace **201** with multiple turns is connected to ground. Since the grounding first end **10** is located at the outermost turn of the spiral conductive trace **201** with multiple turns, there is a spiral conductive trace **221** with a single turn disposed inside the innermost turn of the spiral conductive trace **201** with multiple turns, and the spiral conductive trace **221** with a single turn is electrically connected in parallel to the outermost turn of the spiral conductive trace **201** with multiple turns.

The spiral conductive trace **221** with a single turn is located inside the innermost turn of the spiral conductive trace **201** with multiple turns. That is, the spiral conductive trace **201** with multiple turns is substantially parallel to and surrounds the spiral conductive trace **221** with a single turn. The spiral conductive trace **221** with a single turn has a first end **50** and a second end **60**, wherein the first end **50** corresponds to the first end **10** of the spiral conductive trace **201** with multiple turns.

The connecting traces **213** and **215** may comprise copper, aluminum or alloy thereof and are embedded in the dielectric layer **202** underlying the dielectric layer **204**, thereby connecting the outermost turn of the spiral conductive trace **201** with multiple turns and the spiral conductive trace **221** with a single turn in parallel to form a multi-trace structure. For example, the connecting trace **213** is disposed between the first end **10** of the spiral conductive trace **201** with multiple turns and the first end **50** of the spiral conductive trace **221** with a single turn and is electrically connected between the outermost turn of the spiral conductive trace **201** with multiple turns and the spiral conductive trace **221** with a single turn by conductive plugs **250** and **260** disposed in the dielectric layer **202**, respectively, as shown in FIG. **3**B. Here, the first end **50** of the spiral conductive trace **221** with a single turn is connected to ground through the connecting trace **215**, the conductive plugs **250** and **260** and the signal output/input trace **209'** of the spiral conductive trace **201** with multiple turns. Moreover, the connecting trace **213** is disposed between the outermost turn of the spiral conductive trace **201** with multiple turns and the second end **60** of the spiral conductive trace **221** with a single turn and is electrically connected between the outermost turn of the spiral conductive trace **201** with multiple turns and the spiral conductive trace **221** with a single turn by conductive plugs **270** and **280** disposed in the dielectric layer **202**, respectively, as shown in FIG. **3**C.

Additionally, note that although the spiral conductive trace **221** with a single turn and the outermost turn of the spiral conductive trace **201** with multiple turns are connected in parallel in an exemplary embodiment, the spiral conductive trace **201** with multiple turns may be connected in parallel to more than two spiral conductive traces with a single turn.

In the described embodiments, the multi-trace structure of the spiral inductor is connected to ground. Because the grounding end of the spiral conductive trace **201** has a relatively higher current density (i.e. higher magnetic field) and a relatively lower electric field, the parasitic capacitance between the spiral conductive trace **203** with a single turn and the outermost turn of the spiral conductive trace **201** with multiple turns or the parasitic capacitance between the spiral conductive trace **221** with a single turn and the innermost turn of the spiral conductive trace **201** with multiple turns can be reduced. Moreover, since the innermost turn (or the outermost turn) of the spiral inductor has a multi-trace structure formed by the spiral conductive trace **203** with a single turn (or the spiral conductive trace **221** with a single turn), inductive coupling can be increased and the conductor loss of the spiral conductive trace **201** with multiple turns can be reduced to increase the Q value of the inductor and enhance the inductor efficiency without increasing the thickness of the spiral conductive trace **201** with multiple turns. Accordingly, the Q value of the spiral inductor according to the invention can be increased while maintaining the operational frequency range of the inductor.

While the invention has been described by way of example and in terms of preferred embodiment, it is to be understood that the invention is not limited thereto. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

What is claimed is:

1. A spiral inductor with a multi-trace structure, comprising:

an insulating layer disposed on a substrate;

a first spiral conductive trace with multiple turns disposed on the insulating layer, wherein the outermost turn of the first spiral conductive trace is connected to ground; and

at least one second spiral conductive trace with a single turn disposed on the insulating layer and located inside the innermost turn of the first spiral conductive trace, wherein the second spiral conductive trace is connected to the outermost turn of the first spiral conductive trace to form the multi-trace structure.

2. The spiral inductor as claimed in claim **1**, wherein the first spiral conductive trace is parallel to the second spiral conductive trace.

3. The spiral inductor as claimed in claim **2**, further comprising a connecting trace disposed in the insulating layer for electrically connecting an end of the outermost turn of the first spiral conductive trace to a corresponding end of the second spiral conductive trace.

4. The spiral inductor as claimed in claim **1**, wherein the first and second spiral conductive traces have the same line width.

5. The spiral inductor as claimed in claim **1**, wherein the first and second spiral conductive traces are circular, rectangular, hexagonal, octagonal or polygonal.

6. The spiral inductor as claimed in claim **1**, wherein the second spiral conductive trace and the outermost turn of the first spiral conductive trace are electrically connected in parallel.

* * * * *